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## Gain and Absorption Spectra of Quantum Wire Laser Diodes

## Grown on Nonplanar Substrates

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Quantum wire (QWR) semiconductor lasers, grown by organometallic chemical vapor deposition (OMCVD) on nonplanar substrates, exhibit two dimensional (2D) quantum confinement<sup>1,2</sup> and sub-mA hreshold currents<sup>3</sup>. The *in situ* formation of the wires in these lasers eliminates excessive nonradiative recombination at their interfaces, which is essential for the efficient operation of these devices. One of the expected advantages of QWR heterostructures is the enhanced optical gain and absorption resulting from the increased density of states at the quasi-1D subbands. This feature would make QWR heterostructures useful for applications in low power consumption integrated optoelectronics. Here, we report the first measured gain and absorption spectra of QWR lasers.

The multi-QWR lasers discussed here were grown by OMCVD on V-grooved substrates<sup>2</sup>. Their active regions consist of 4 crescent-shaped GaAs wires, placed at the center of a 2D, graded index AlGaAs optical waveguide (see Fig. 1). A band structure model of these wires yields electron-heavy hole QWR subband transitions separated by 19meV, with an effective wire width of 15nm for the ground electron state. The subband structure was evident in the amplified spontaneous emission and lasing spectra of the devices, with observed transition energies in good agreement with the calculated values<sup>2</sup>.

Modal gain and absorption spectra were evaluated from measured fringe visibility of the longitudinal modes<sup>4</sup> in Fabry-Perot 4-QWR lasers. Devices of 260 $\mu$ m cavity length were cleaved and high-reflection (HR) coated using gold to ensure large spectral bandwidth of high reflectivity. Lasing occurred predominantly at 806nm (1.54eV), corresponding to the third ( $l=2$ ) e-hh QWR subband transition<sup>2</sup>, with threshold current of 6.5mA (see Fig. 2). The TE-polarized modal gain spectra (compensated for waveguide scattering and free carrier absorption losses) shown in Fig. 3 were obtained for the same device, at various diode currents below and above threshold. The calculated positions of the e-hh QWR subband transitions ( $l=0,1,2,\dots$ ,  $\Delta l=0$ ) are indicated by the arrows. Several absorption dips are evident at the QWR subbands, particularly at lower currents and higher energies. These absorption features reduce in depth with increasing current as the QWR subbands become populated by carriers. Above transparency level, the absorption dips turn into gain peaks whose magnitudes saturate at the cavity mirror loss value. A maximum modal gain of  $\sim 20\text{cm}^{-1}$  was measured at 1.54eV ( $l=2$ ) at or above threshold.

Using a two-dimensional waveguiding model, we calculated a total optical confinement factor of  $6.8 \cdot 10^{-3}$  for the 4 wires. This yields an average *material* gain value of  $\sim 3000\text{cm}^{-1}$  per wire, which is at least as large as reported gain constants in quantum well structures<sup>5</sup>. Furthermore, our models show that higher modal gains can be achieved by optimizing the waveguide structure to improve the optical confinement, and by minimizing the wire-to-wire variations to reduce inhomogeneous broadening. The combined effects of higher gain and extremely small active volume in such optimally designed QWR lasers should lead to threshold currents in the  $\mu\text{A}$  regime. In addition, The enhanced absorption features we have observed in these QWR structures should be useful for applications in low power consumption optical modulators and switches.

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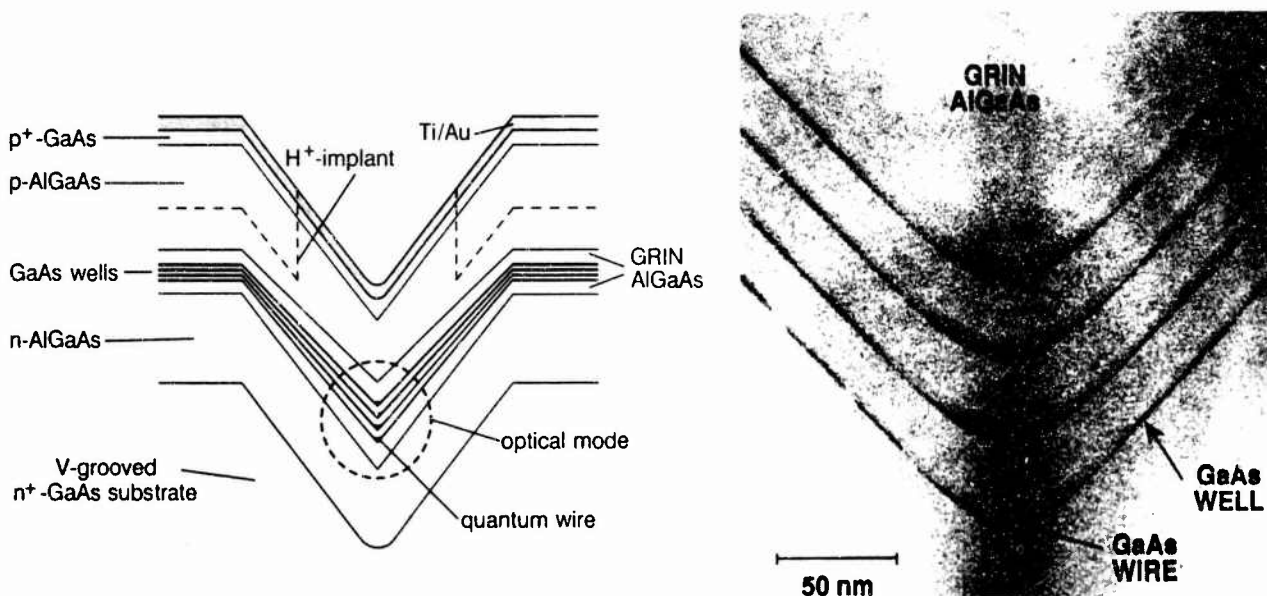


Fig.1: Schematic (left) and transmission electron microscope (right) cross sections showing the layer structure and the vertically-stacked, crescent-shaped wires at the core of the 4-QWR laser.

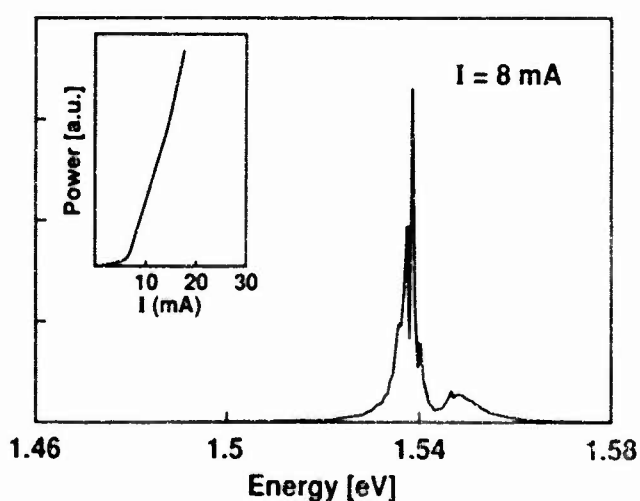


Fig.2: Spectrum of a 260μm long, HR coated 4-QWR laser above threshold. Inset shows the light versus current characteristic (pulsed operation).

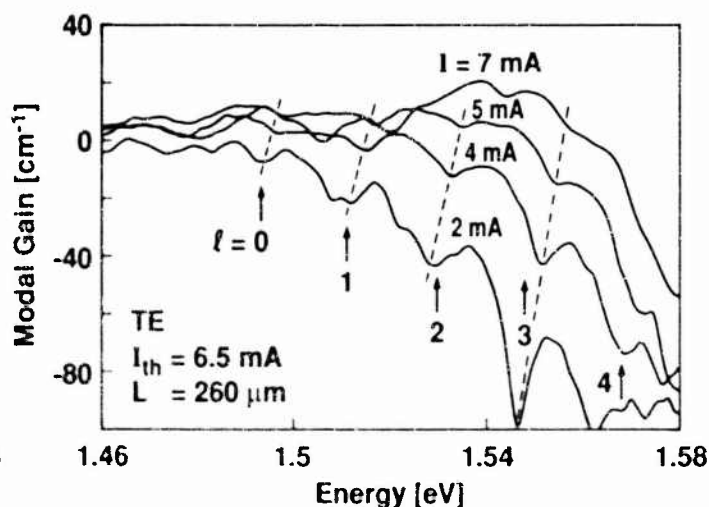


Fig.3: Measured modal gain spectra of the 4-QWR laser for TE polarization at various diode currents.